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MONTEREY, CALIFORNIA

THESIS

OPTIMIZING BANDWIDTH IN TACTICAL COMMUNICATIONS SYSTEMS

by

Criston W Cox Jr.

June 2005

Thesis Advisor:	William Kemple
Second Reader:	John Osmundson

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13. ABSTRACT (maximum 200 words)

Current tactical networks are oversaturated, often slowing systems down to unusable speeds. Utilizing data collected from major exercises and Operation Iraqi Freedom II (OIF II), a typical model of existing tactical network performance is modeled and analyzed using NETWARS, a DISA sponsored communication systems modeling and simulation program. Optimization technologies are then introduced, such as network compression, caching, Quality of Service (QoS), and the Space Communication Protocol Standards Transport Protocol (SCPS-TP). The model is then altered to reflect an optimized system, and simulations are run for comparison. Data for the optimized model was obtained by testing commercial optimization products known as Protocol Enhancement Proxies (PEPs) at the Marine Corps Tactical Systems Support Activity (MCTSSA) testing laboratory.

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OPTIMIZING BANDWIDTH OF TACTICAL COMMUNICATIONS SYSTEMS

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Captain, United States Marine Corps
B.A., The Citadel 1999

Submitted in partial fulfillment of the
requirements for the degree of

**MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY
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Current tactical networks are oversaturated, often slowing systems down to unusable speeds. Utilizing data collected from major exercises and Operation Iraqi Freedom II (OIF II), a typical model of existing tactical network performance is modeled and analyzed using NETWARS, a DISA sponsored communication systems modeling and simulation program. Optimization technologies are then introduced, such as network compression, caching, Quality of Service (QoS), and the Space Communication Protocol Standards Transport Protocol (SCPS-TP). The model is then altered to reflect an optimized system, and simulations are run for comparison. Data for the optimized model was obtained by testing commercial optimization products known as Protocol Enhancement Proxies (PEPs) at the Marine Corps Tactical Systems Support Activity (MCTSSA) testing laboratory.

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ACKNOWLEDGMENTS

The author would like to acknowledge the financial support of the 3rd Marine Division and the Marine Corps Tactical Systems Support Activity (MCTSSA) for their contributions of $10,000 each. Funds were used to support travel and training in support of this research. Also, much of this research would not have been possible without the support of the following:

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Lt Col John Cook, 3rd Marine Division G6,

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Mr. Mark Bacharach and Mr. Andre Johnson of Booz Allen Hamilton’s NETWARS Program Office,

Captain Mike Ohlegher of DISA,

Dr William (Bill) Kemple, NPS.

A special thanks to my wife, Theresa, and my three children, who patiently sacrificed much in the name of “Dad’s thesis.”

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EXECUTIVE SUMMARY

Command and Control (C2) techniques and procedures radically changed with the emergence of Net-centric capabilities. In just a ten year period, the author witnessed a complete revolution in Division level C2. In 1993, Radio operators hand-delivered messages to staff officers, who plotted points on individual wall-sized map boards. Information sharing meant walking over to the other staff officer's cubicle and telling him what was deemed necessary for him to know. Today, information is more centralized, enabling it to be efficiently shared, filtered, and accessed as needed. C2 systems are displayed via projectors or plasma televisions, and can be displayed and sorted via overlays for specific views on the staff officer's laptop. Instead of the Commanding General walking around to each section for updates, he can sit before one screen, while each staff officer briefs from the same Common Operational Picture.

The revolution of netcentric C2 has been effectively realized by both the war fighting staffs and the communicators who provide the networks on which these capabilities reside. However, the communications community has not yet grasped standardized methods for optimizing the systems to get the most out of them. This thesis analyzes various methods designed to optimize tactical communications systems and provide significantly higher levels of service with currently fielded systems.

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I. THE PROBLEM WITH CURRENT USMC TACTICAL NETWORKS

A. BACKGROUND

The Unites States Marine Corps has made a tremendous transformation in the way the Combat Operations Center (COC) is operated, and how commanders command and control (C2) the battlefield. The COC is operated of the Commander’s principle staff, and serves as the nucleus of his C2 functions. Up to the early to mid 1990’s, the primary means of communications in the COC was single channel radio. Junior enlisted Marines transcribed radio messages onto a “yellow canary” form, and promptly handed it off to the staff officer for action. Each section used its wall-sized map boards to maintain situational awareness by marking positions with color-coded tacks. Information sharing meant that a staff officer was obligated to walk over and deliver the information personally.

Today, technological implementations have radically changed COC operations. Flat screen 42-inch plasma monitors and large screen projectors provide visual support, such as a near real-time Common Operational Picture (COP) of the Global Positioning System (GPS) equipped units as they move across the battlefield. Situational Awareness (SA) is provided by a multitude of systems, to include a web-enabled database that is fed by higher, adjacent, and supporting units as they report events. At the Regimental level and above, data systems have become the primary means of communications, providing e-mail, C2 systems, and web-based applications. Even the highly-mobile infantry battalions, which still rely primarily on single channel radio with limited data while

on the move, are becoming more and more reliant on data systems in the Battalion COC once in a static position. For example, just prior to retaking Fallujah in November 2004, two of the three infantry battalions observed operating in Fallujah and Ramadi had saturated their 256 kbps SIPRNET (Secure Internet Protocol Routed Network) at 98 percent utilization. The radio remote units associated with single channel radio nets are barely apparent above the Regimental level COC, almost a defunct byproduct of days gone by.

B. THE LEARNING CURVE

All of the applications, email, and C2 systems that Marines so heavily depend upon in the field ride over the network, which is designed, built, and managed by communications Marines. The Marine Corps as a whole has endured a steep learning curve over the past decade to embrace technological advances, but none more so than the communications Marines. Each time they deploy to the field, they reprogram routers, rebuild the Exchange servers(mail), Domain Name Servers (DNS), and domain controllers, create and manage all user accounts, put user’s computers on the network, and manage the Deployed Security Interdiction Device, an Intrusion Detection System (IDS) and firewall system. Data communications Marines are good at what they have been trained to do, but their training is limited in scope. They are not taught how to manage Quality of Service (QoS) features of our existing Cisco routers, such as Priority or Custom Queuing strategies. Layer 2 (of the Open Systems Interconnection model (OSI model)) management of switches generally does not happen, and the Local Area Networks (LANs) behind the

firewall are treated as plug and play systems. This thesis analyzes various network optimization technologies that the USMC could implement to more proactively manage these systems and maximize the limited bandwidth.

C. THE PROBLEM AND PURPOSE

Tactical networks are becoming increasingly saturated with users and applications as the need for information exceeds the capabilities of the systems that provide it. "At the peak of [OIF I], DISA (Defense Information Systems Agency) claimed that 3 Gbps of satellite bandwidth was being provided to the theater,… 30 times the bandwidth made available during Desert Storm."[1] A typical satellite connection to a Standardized Tactical Entry Point (STEP) is 1024 kbps. This is multiplexed to provide Defense Information System Network (DISN) services[2] to many tactical users. After being multiplexed/demultiplexed into separate services, the data networks only receive a portion of the bandwidth, typically less than 384 kbps. To put this in perspective, anywhere from 50 to more than 100 users may be using a circuit that has the bandwidth equivalence of a residential Digital Subscriber Line (DSL) connection. In addition, due to the adverse effects that high bit errors and latency associated with satellite transmissions cause for TCP (Transmission Control Protocol), actual traffic throughput capability is even less than the allotted bandwidth. (The problems with TCP over Satellite will be discussed further in Section III). Given the crucial role

[1] Leland Joe, Isaac Porche III, *Future Army Bandwidth Needs and Capabilities,* p. 11, RAND Corporation, 2004.

[2] DISN services normally extended to the Division COC include: Digital Truck Group (DTG) for secure and nonsecure telephone service from the Defense Switched Network (DSN), Secure Internet Protocol Router Network (SIPRNET) and Unclassified but Sensitive Internet Protocol Router Network (NIPRNET), and Video Teleconference (VTC).

communications systems play in maintaining information superiority and commanding and controlling the battlefield, bandwidth has become a critical asset requiring deliberate management techniques.

1. The Problems with Current Methods for Meeting Bandwidth Requirements

Senior communicators recognize the impact of growing user requirements, and are confronting the demands with various COTS solutions and technologies, from simply leasing more bandwidth to various WAN acceleration products. Moreover, acceleration products are often incompatible between vendors due to proprietary standards, causing interoperability issues when units purchase different optimization solutions. For example, during OIF I, MARCENT purchased SkyX accelerators to terminate an Intel link between 3rd Marine Air Wing and 1st Marine Expeditionary Force (I MEF)[3], the 24th Marine Expeditionary Unit (MEU) purchased Expand accelerators, and the STEP sites implemented the ComTech Turbo IP Accelerators (I MEF also had Expand Accelerators). Each of these products used different protocols at that time, which were not interoperable and could only be used on internal point to point links with like devices on each end. Despite significant performance increases observed on internal links, links to adjacent units, Joint Task Force (JTF) elements, and the STEPs remained congested due to incompatible proprietary standards. If everyone were using a standard solution, the whole system, rather than a few selected links, would perform more efficiently.

[3] EMAIL: LtCol Mark Bryant. FW: Request For Information BryantMH@mcsc.usmc.mil October 13, 2004

DISA has established the Space Communications Protocol Standards - Transport Protocol (SCPS-TP), (*MIL-STD-2045-44000 and Consultative Committee for Space Data Systems CCSDS-714.0-B-1*) as the only approved form of TCP acceleration for mitigating the deficiencies due to the satellite link, but they should also provide further guidance on the use of approved compression and caching technologies, which would provide far greater throughput than SCPS-TP alone. In absence of such guidance, unit's requests to use compression or caching technologies such as those featured on SkyX and Expand, are denied. According to the MARCENTCOM G-6 Operations Officer during OIF I:

> Sky-X boxes were purchased by MARFORPAC/MARCENT (i.e. I signed the purchase request). It was our hope that we could use them ISO our GMF links into the STEPs, but DISA shot us down - they did not like the caching done by the Sky-X, especially when we were pulling SIPR traffic from them. So, we only used on a pt-pt KU shot (8 mbps) between the Wing and I MEF . . . That was our means for passing raw intel taken from the FA-18's to the I MEF intel cell at Camp Commando…[4]

The caching aspect should not be treated any differently than the stored data on a SIPRNET server or client's hard drive. Once an accelerator touches a classified network, it should simply be treated with the same security precautions and standards as we do any other devices placed on the SIPRNET, such as the popular mini-thumb USB hard drives so commonly used in Iraq.

Another solution to increasing bandwidth is to simply buy more, which has proven to be inordinately expensive comparative to the cost of achieving comparable data rates

[4] Email: LtCol Mark H Bryant, SUBJ: *RE: FW: Request For Information*, January 20, 2005. mark.h.bryant@usmc.mil

by maximizing our existing systems with the WAN acceleration technologies demonstrated in this thesis. MARCENT's Universal Need Statement (UNS) to acquire 8Mbps Deployed Ku-band Earth Terminal (DKET) and Fly-away Ku-band Earth Terminal (FKET) terminals and supporting Technical Control Facility, estimated procurement costs at $10,762,000, not including the 1.2 million paid yearly for each Ku circuit's bandwidth.[5] I MEF also procured additional bandwidth at an estimated 12 million dollars per year for their five commercial Ku band links.[6] One goal of this thesis is to demonstrate how comparable data rates can be achieved at a fraction of the monthly cost of a single leased commercial line by purchasing COTS optimization products, which could be used on all future exercises and operations.

Until Headquarters Marine Corps (HQMC) provides further guidance, G-6 officers can only influence policy and purchasing decisions within their scope of responsibility. The effort of this thesis is to provide an overview of the various techniques and technologies available, provide performance and interoperability perspectives, and demonstrate network optimization metrics through modeling and simulation.

[5] Email: LtCol Mark H Bryant, SUBJ: *RE: FW: Request For Information*, March 3, 2005. mark.h.bryant@usmc.mil

[6] Email: Capt Billy Cornell, SUBJ: RE: Request For Information, March 3, 2005. Capt Cornell was the I MEF G-6 Operations Officer during OIF I. His cost are estimated as follows: (4) Ku Satellite Terminals using the Intelsat Constellation: 1.2M per for 6 months of access (total of 28 Mbps Bandwidth, two terminals with 8Mbps, and two with 6Mbps) x2 for one year Total = 9.6M. A fifth Ku terminal at Marine Logistics Command cost an additional 1.2M, for a total of 12 million.

Because USMC Communication and Information Systems Officers (0602) are the target audience, the remainder of this thesis will use the common vocabulary understood by that community without elucidation.

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II. CONDUCT OF THE STUDY

A. DATA COLLECTION

In support of this thesis, the author made several Temporary Additional Duty (TAD) trips for additional training and to observe and collect data from tactical networks, to include:

- Exercise Cobra Gold 2004 (CG 04) in Thailand
- Ulchi Focus Lens (UFL 04) in South Korea
- Operation Iraqi Freedom II (OIF II) in Iraq
- 1st Marine Division G-6 Office and the Marine Corps Tactical Systems Support Activity (MCTSSA) at Camp Pendleton California
- The Armed Forces Communications and Electronics Association (AFCEA) West 2004 Convention to attend the Department of Defense Architecture Framework (DODAF) Professional Development Course in San Diego Ca.
- Flagstaff Arizona to assist in research conducted by Captains Gilbert Garcia and David Joseforsky on the use of Free Space Laser Optics to tie in voice and data from antenna hill to the Unit Operations Center (UOC).
- Booz Allen Hamilton's (BAH) training on the Network Warfare Simulation (NETWARS) Program at the DISA office in Washington DC.
- Intense Schools Cisco Certified Networks Administrator (CCNA) and Certified Wireless Network Administrator (CWNA) courses San Diego Ca.[7]

Observations from these experiences are referenced throughout.

[7] These courses were funded by Mr. Brian Steckler, NPS, under the Nemesis Wireless Warfare Project. All other funding provided by MCTSSA and 3rd Marine Division.

1. Data Collection Utilities

Three utilities were employed to capture network statistics and data. The model discussed in Chapter V represents measures of performance observed using these tools.

a. Network Traffic Analysis System

The Network Traffic Analysis System (NTAS) is a Government Off-the-Shelf (GOTS) system developed using Commercial Off-the-Shelf (COTS) products. NTAS collects network traffic data from SNMP/RMON/RMON2[8] compatible network devices, NetFlow data from Cisco routers, and network configuration data from routers via SNMP. It employs the Net-Centric concept toward the collection, distribution, and access to network performance and topology information via standard data transfer and Web client interfaces[9]. Unlike other software used, NTAS is a suite of applications preconfigured on a server, requiring trained personnel to install and maintain. NTAS equipment and personnel support was provided during CG 04, UFL 04, and OIF II by DISA's Cross-Program Engineering Branch (GE323). The illustration below depicts the general concept of the NTAS server both collecting traffic and presenting results in a web-based GUI (Graphical User Interface).[10] Because the NTAS is a device on the network, access to the OIF NTAS can be granted if the IP address, username, and password are known.

---

[8] Simple Network Management Protocol, Remote Monitor, Remote Monitor version 2

[9] ConOps for NTAS, Cross-Program Engineering Branch (GE323) GIG Enterprise Services, Defense Information Systems Agency

[10] Illustration taken from the MARFORPAC UFL '03 COP Analysis Out-brief Presentation, Unclassified, presented 19 November 2003 by Major E. Thomas Powers, former NETWARS Study Lead.

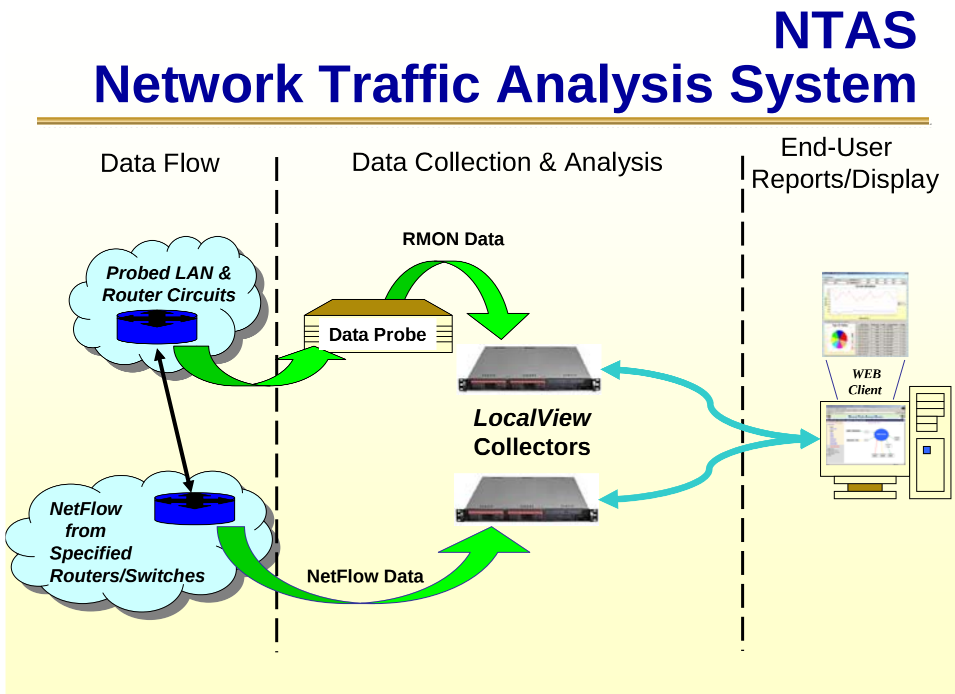

Figure 1. NTAS Collection Scheme

b. SolarWinds

SolarWinds Engineer's Edition Version 7 is a suite of networking management software containing Network Discovery, Fault Monitoring, Performance Monitoring and Performance Management applications.[11] SolarWinds proved to be a very powerful tool for network analysis, but can be dauntingly technical for inexperienced analysts. This version of SolarWinds better serves as a tool for analysis and troubleshooting than for network monitoring in the sense we currently employ What's Up Gold or HP Openview. What's Up Gold generates ICMP traffic on the network, and uses response times from other nodes to monitor network health, which is a more reactive, rather than proactive approach to network management. SolarWinds uses Simple Network Management Protocol (SNMP), which also adds traffic

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[11] http://SolarWinds.net/Tools/Engineer/index.htm] January 05

to the network, but pays far larger dividends by giving network administrators greater ability to identify problems before the network goes down, instead of waiting until an icon shows up red to begin troubleshooting. The Engineers edition used featured forty seven different tools, such as Device discovery, which provides a list of host names and IP addresses in use, circuit utilization percentage graphs, errors, and transmit and receive rates, and a host of Cisco, DNS, and CPU and bandwidth gauges and tools.

c. Ethereal

Ethereal Network Protocol Analyzer is a free, open-source, packet capturing utility. Ethereal passively captures raw data, allowing analysis of frames, packets, and protocols traversing the network, as depicted in Figure 2. Ethereal data can also be converted into Application Characterization Environment (ACE) threads, for visualizing, analyzing, and troubleshooting networked applications.[12] ACE threads can be imported in NETWARS to represent actual traffic flows; however that technique was not employed for this study due to the classification of the RIPRNET and SIPRNET traffic, as well as the size and complexity of the network. That utility was not discovered until after UFL. Ethereal was employed on the OIF II network to determine what percentage of each of the typical protocols comprised the traffic. The results observed influenced the background traffic loading percentages of the model.

[12] Ace User Guide for IT Guru, OPNET IT GURU Software Documentation

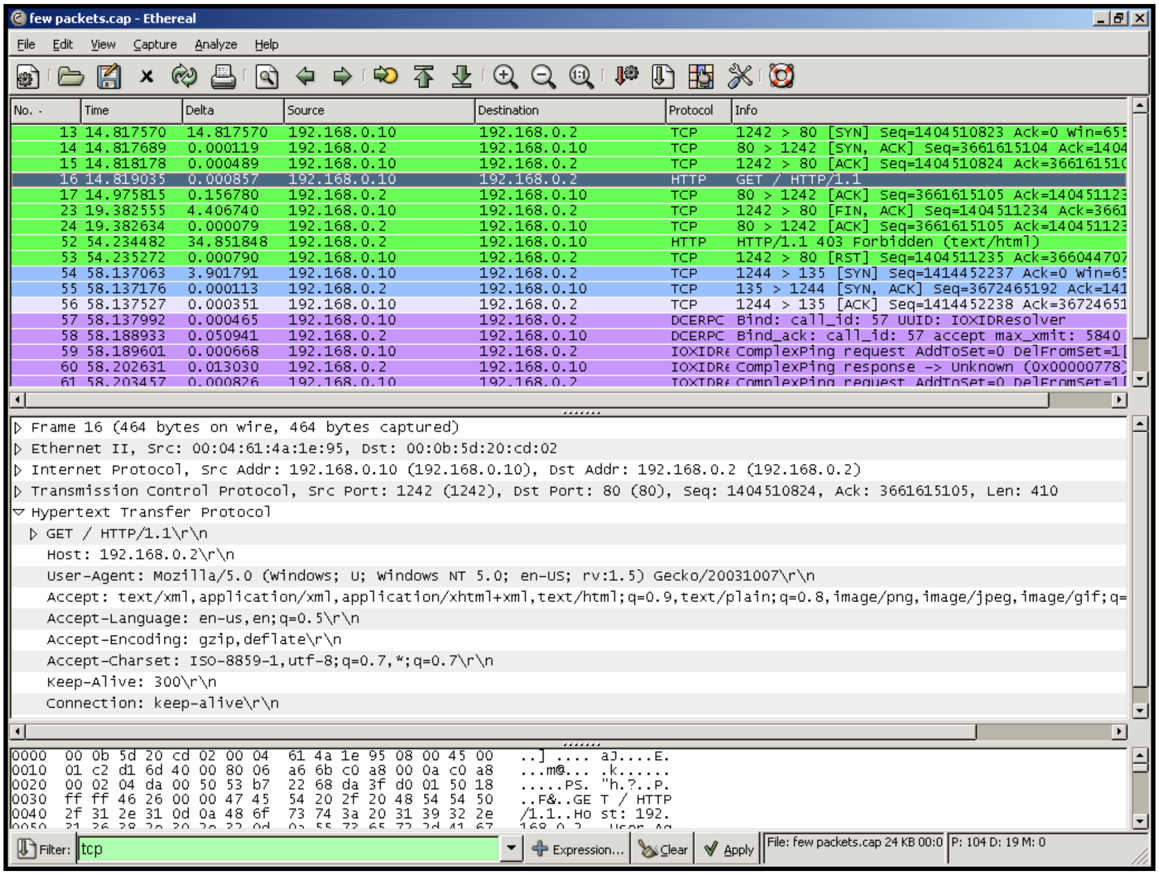

Figure 2. Ethereal Screen Capture

B. STUDY OVERVIEW

To demonstrate the level of service being provided on current networks, a model of a typical tactical network was constructed using NETWARS. Designed using traffic profiles and circuit utilization percentages observed and collected during Cobra Gold 04, UFL 04, and OIF II, the model is capable of producing statistical data by simulating traffic traversing the network. Optimization techniques and technologies are then researched and tested, and the model is modified to reflect the improvements observed during testing. The simulation is run once again, and the resulting data is compared to the previous results to

demonstrate the expected benefits of a layered optimization approach. The NETWARS model and results are presented in Chapter V.

III. OPTIMIZATION TECHNOLOGIES

A. COMPRESSION

Compression of data reduces the total amount of traffic that traverses the network, thereby reducing congestion. Network compression affects all (previously uncompressed) data prior to transmission, similar to the way WinZip reduces the size of individual files or folders. It is common to see vendors advertise 60 to 80 percent compression ratios, and according to the independent Information Technology (IT) consulting company META Group, an average compression ratio of 60 percent is not unusual. Meta Group provides the following example and chart to demonstrate compression rates by application: “If the data destined for a 100% utilized 1.5 Mbps T1 link is 60% reducible, BCO [Bandwidth Compression and Optimization] could instantly reduce traffic contention and add 40% unutilized capacity for peak loads or new applications. Assuming additional traffic was equally compressible, the equivalent capacity of this link would be 1/(1 - 0.60) x 1.5 Mbps = 3.75 Mbps.”[13]

Proprietary compression algorithms require a like device to decompress, but open-source algorithms should be interoperable between different vendors.

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[13] Peter Firstbrook, META Group, White Paper, Bandwidth Compression and Optimization: Increasing WAN Capacity and Control Without Increasing Expenses, pp. 6-7, June 2003.

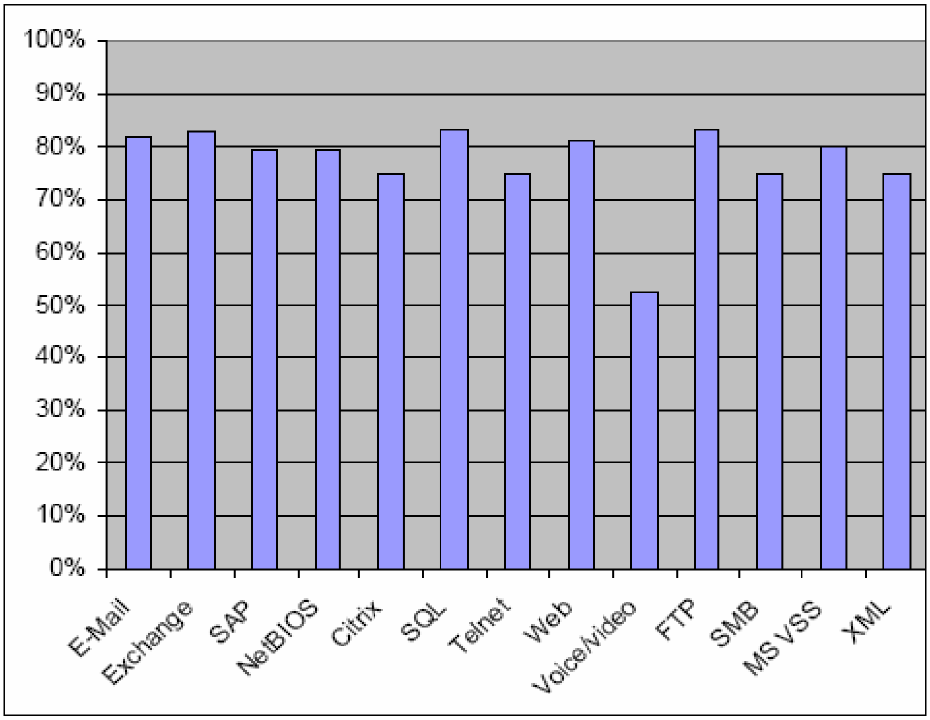

Figure 3. Compressibility of Various Applications (From Ref. 13)

B. CACHING

Caches are application-specific proxies that store content for future reference, such as HTTP, FTP, DNS, and streaming media. Data accessed across the network is stored locally so that any future requests from users of the LAN will pull from the cache server instead of consuming bandwidth of the transmission system. Caching only improves performance on data that has traversed the network and been stored, so the benefits of caching increase with time as the content builds. While compression cannot reduce the amount of bandwidth consumed by pre-compressed files such as MPEG and JPEG formats, caching can.

Most communications officers are already familiar with web proxies placed locally to service the LAN. While this technique does help, it does not compare to the benefits of

WAN caching techniques that utilize tokens to represent bit patterns. Rather than just locally caching HTTP traffic, technologies such as Peribit's Molecular Sequence Reducer (MSR) cache at the bit level by representing bit sequences with symbols. For example, an email with a 2 megabyte PowerPoint presentation may be represented by a 4 byte word. Rather than receiving the full PPT file, only the characters representing that file are transmitted.

C. QUALITY OF SERVICE

A broad term for bandwidth management techniques, QoS refers to queuing strategies, prioritization, packet shaping/traffic shaping, policies, and flow control designed to counter the inefficiencies of the internet's *best effort* service. During periods of high congestion, *best effort* service drops packets, requiring TCP based applications to retransmit, and offers no assurance that application traffic is received.[14] As the default service, "*best effort* does not deny entry to traffic, so as the load levels increase, the network congestion levels increase, and service-quality levels decline uniformly."[15] This can become a significant problem on tactical networks, where BERs can be as high as e-5[16] and latency as high as 2000ms.[17] "IP QoS functions are intended to deliver

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[14] Srinivas Vegesna, *IP Quality of Service*, p. 5, Cisco Press, 2001.

[15] Geoff Huston, "*Quality of Service-Fact or Fiction?*" Internet Protocol Journal, Vol 3, Number 1, 2000.

[http://www.Cisco.com/warp/public/759/ipj_3-1/ipj_3-1_qos.html]. Date not given, last accessed Feb, 2005.

[16] The notation e-5 is also represented as 1x10^-5, or 1 error for every 100,000 bits.

[17] Possible latency of EHF MILSTAR systems considering RTT, plus cross-linking and interleaving processing time as confirmed by Mr Scott McCoy, an engineer with Titan Corporation who supports MARCORSYSCOM on matters pertaining to EHF systems.

guaranteed as well as differentiated Internet services by giving network resource and usage control to the network operator.[18]

Unlike compression, QoS features can be implemented on just one end of the WAN to more closely manage existing bandwidth. The majority of Cisco devices come with QoS features included in the IOS (Internetwork Operating System), and can be configured through the Command Line Interface (CLI). However, the Marines are generally not trained on these techniques. Recognizing the need to optimize tactical networks, I MEF took proactive measures to prepare for their redeployment to Iraq.

Prior to re-deploying to OIF II, I MEF purchased new Cisco routers and layer 3 switches for the MEF and its MSCs. During a TAD visit to Camp Pendleton in January 2004, the author observed the new systems preconfigured in a lab environment to work the bugs out and provide additional training prior to deploying. Cisco representatives were present, walking the Marines through configuration of QoS parameters. However, by October 2004, the only setting resembling a QoS effort was a VLAN dedicating priority to a VTC circuit.[19] The router administrator conjectured that this was due to troubleshooting by the process of elimination, where Marines deleted configurations not absolutely required.

Many PEPs feature QoS settings, some of which include a GUI interface, allowing administrators to easily prioritize traffic by protocol, subnet, or VLAN through

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[18] Srinivas Vegesna, IP *Quality of Service*, p. 5, Cisco Press, 2001.

[19] The author observed networks at I MEF, 1st MarDiv, RCT 1, and 2nd Battalion/5th Marines while TAD in Iraq.

check boxes or radio buttons. Simplifying the interface for configuring QoS parameters and more advanced router training could help to shrink the QoS knowledge gap for Marines.

D. NETWORK MONITORING AND ANALYSIS

Proactive network monitoring and analysis is an effective way to identify bottlenecks and sources of heaviest traffic. Monitoring and analysis tools do not physically enhance the network, but rather, offer an interface to the managers to gain a better understanding of what is happening on the network so that failures and bottlenecks can be prevented before they occur. Knowing circuit level utilization rates also allows decision-makers to reallocate unused bandwidth to higher priority or overly saturated links.

The requirements for effective network management are understood at all levels and branches of service. During Cobra Gold 2004, the Division G-6 used a Commercial Off the Shelf (COTS) solution called the Bandwidth Management Allocation Controller (BMAC), a packet shaping and Application layer QoS management system based on Packeteer that can prioritize traffic based on protocols. The BMAC presents a good picture of the network as a whole, but seemed challenging to configure for the one trained operator present during the exercise. The Combined Joint Task Force (CJTF) used What’s Up Gold, while others used HP Open View, SolarWinds, and NTAS. Each of these programs presents a slightly different and valuable picture of what is happening on the network. The challenge is in interpretation of the data, and standardization of which system to use. The solution to interpreting the data

produced can be overcome through training. The question is, on which system to train. Different units have different applications, thus seeing different pictures of network health. Observing messages between the Army-led Joint Communications Control Center Systems Control (JCCC SYSCON) and the Combined Marine Forces Systems Control (CMARFOR SYSCON), it became obvious that the two were not seeing the same status of the network due to the different applications being used, and the means by which that data is collected, presented, and interpreted.

The issue created unnecessary tensions, and was well noticed by the staffs involved. The situation was epitomized by a cartoon which emerged during the exercise, relating it to The Blind Men and the Elephant fable because each unit was seeing their specific piece of data, but failing to see and understand the status of the whole network. To resolve this issue, we must move toward a standardized application that provides the best qualities of all the available tools, as well as direction from the Pentagon Joint Staff J-6 to transition all services to use the designated system. This concept is permeating all branches of service as the Joint Staff J-6 wrestles with the fielding and implementation of the Joint Network Management System (JNMS).

E. PROTOCOL ENHANCEMENT PROXIES (PEPS)

1. The Problem with TCP Over Satellite

TCP is a connection oriented protocol, designed to control congestion and ensure the successful delivery of packets. The throughput of a single TCP connection has a maximum limit that is directly dependent upon the Bandwidth Delay Product (BDP) and the Round Trip Time (RTT). The

effect of a high BDP is explained in a technical report produced by The Center for Satellite and Communication Networks:

> Consider as an example a T1-rate (1.544 Mbps) channel through a geostationary satellite, at 22,300 miles altitude. In such a system, the propagation delay from the earth's surface to the satellite exceeds 120 ms. Accordingly, more than 120 x 4=480 ms elapses between the time a byte is sent in this system and the acknowledgment returns via the satellite. Multiplying this “roundtrip-time” by the data transmission rate yields a so-called bandwidth-delay product of more than 1544000 x 0.480=741120 bits...[741 kbps]. The bandwidth-delay product represents the maximum amount of information which can simultaneously be in transit between the endpoints of the communication.[20]

While the previous example used 480 ms to represent a minimum RTT, 560 ms is more representative of the DSCS satellite system. Applying this more toward a tactical network scenario, the BDP of multiplexed 384 Kbps SIPRNET connection over a DSCS system would yield a BDP of 384000 bps x .560 seconds = 215040 bits or 215 Kbps, which is only 56% of the available bandwidth.

The RTT and window size affects throughput based on the formula:

throughput = window size / RTT

“Therefore, using the maximum window size of 65,535 bytes [64 Kbs] and a geosynchronous satellite channel RTT of 560 ms, the maximum throughput is limited to:

[20] M.H. Hadjitheodosiou, A. Ephremides, D. Friedman, The Center for Satellite and Hybrid Communication Networks, CSHCN T.R. 99-2, (ISR T.R. 99-9) *Broadband Access via Satellite*, p. 21, Date not given.

65,535 bytes / .560 seconds = 117,027 bytes/second."[21]

This means that no matter how much additional bandwidth is allocated, throughput using DSCS satellites is limited to approximately 117 Kbps per TCP connection. Applying the throughput formula above to the MILSTAR constellation, which may have as much as 2000 ms RTT due to cross-linking, processing, and interleaving, the severely limited capabilities of our SMART-T links is demonstrated: 65,535 bytes / 2 seconds = 32767.5 bytes/second (32 Kbps).
No matter how much bandwidth is engineered into the SMART-T link, only 32 Kbps will be utilized per TCP connection.

It should be noted that some applications are capable of multiple simultaneous connections, and will compete for more of the available bandwidth. This can "increase throughput efficiency to 92%, with the other 8% accounted for in overhead... therefore, the effective window is equal to the sum of the individual windows."[22] However, the number of simultaneous TCP connections allowed is unique to each application and cannot be relied upon as a solution to the TCP over SATCOM problem.

The reason BDP and RTT so adversely affect TCP are due to the same mechanics designed to make TCP an efficient layer 4 protocol over wired and terrestrial links, particularly the slow start mechanism and congestion avoidance. After transmitting packets, TCP waits for an Acknowledgement (ACK) from the distant end before

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[21] M. Allman, D. Glover, L. Sanchez, Network Working Group Request for Comments: 2488, *Enhancing TCP Over Satellite Channels Using Standard Mechanisms,* p. 12, January, 1999.

[22] Roland Marc Selmer, Internet Via Satellite, http://www.selmatex.com/Publications/Internet%20Via%20Satellite.pdf Last accessed May 1, 2005, date of publication not given.

transmitting the next burst. The size of the segment that can be transmitted is determined by the congestion window (cwnd), which is set during the initial stages of the connection.[23] Each time an ACK is received, the cwnd increases by a single segment, exponentially increasing the size of the sliding window up to the maximum window size of 64 kbps.[24] This process, known as slow start, ensures connections ramp up slowly, rather than suddenly congesting the available bandwidth. If the ACK is not received within a specified time window, called the Retransmit Time Out (RTO), TCP retransmits, and the slow start mechanisms starts over. This process was designed for low latency / low BER ($10*e^{-7}$) wired or terrestrial networks. However, the harsh signal conditions of satellite links ($10*e^{-5}$ BER and 500ms+ latency) adversely affects TCP's slow start congestion control algorithm, causing it to repeatedly ramp up and drop. The effect resembles a saw tooth pattern, where the area beneath the curve is the average throughput, which is significantly lower than the bandwidth allotted.

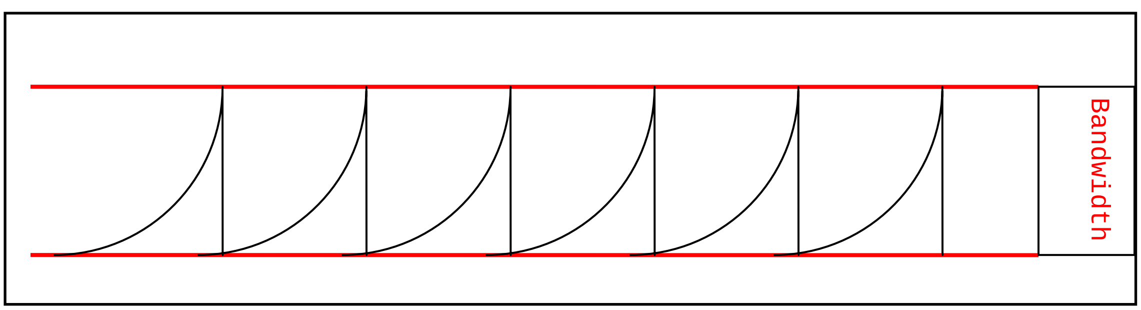

Figure 4. Throughput Average due to TCP Window Sizing

[23] M. Allman et al. Network Working Group, Request for Comments: 2581, *TCP Congestion Control*, 1999

[24] Roland Marc Selmer, Internet Via Satellite, http://www.selmatex.com/Publications/Internet%20Via%20Satellite.pdf Last accessed May 1, 2005, date of publication not given

2. Using PEPs to Overcome TCP Over SATCOM Limitations

Generally, there are two methods to circumvent the problems of TCP over satellite: TCP spoofing, or altering the TCP protocol itself into a form more suited to traverse the space segment. When spoofing is used, fake ACK responses are returned locally to rapidly reply to SYN (synchronization) and PSH (push) frames, completing the handshake and keeping the TCP window size higher. Alternatively, the open-standard Space Communications Protocol Standards (SCPS) protocol is “essentially standard TCP augmented by a set of extensions and enhancements that consist of both implementation and specification changes.”[25] The illustration below depicts the concept of shortening ACK response times by locally spoofing.[26]

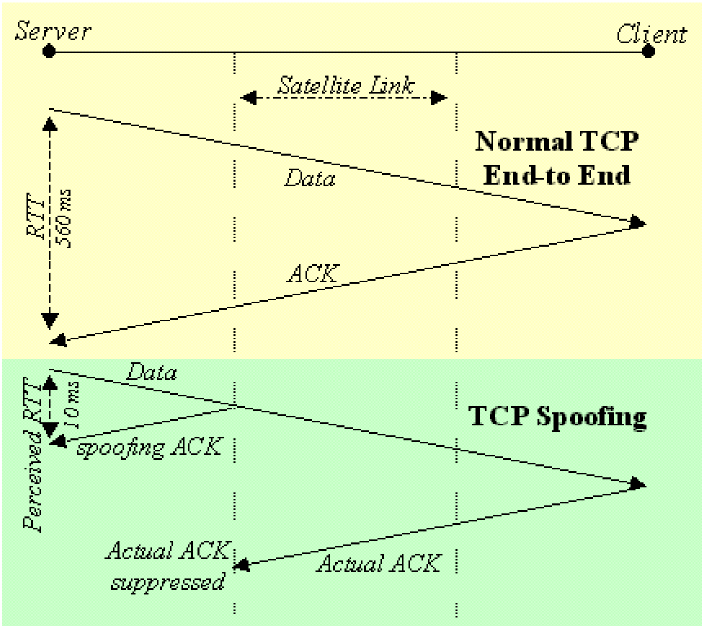

Figure 5. Spoofing TCP Acknowledgments (from Reference 26)

[25] Darrell E. Ernst, Robert C. Durst, US Space Command (USSPACECOM), SCPS D71.51-Y-1, *Space Communications Protocol Standards (SCPS) Bent-Pipe Experiment Report*, p. 145, May, 1996.

[26] SFC Doug Inglis *WHITE PAPER: TCP/IP Performance over Geo-SATCOM Links*, EU32 CONEX (DISA-EUROPE STEP Manager, date not given.

Many PEPs include several of the features identified in the paragraphs above, offering a layered approach to network optimization. Therefore, the term PEP has become a general term for WAN acceleration products, and may do much more than just TCP enhancement.

3. PEP Standards and Background

There are several vendors producing PEPs using both the SCPS Transport Protocol implementation and proprietary solutions. Recognizing the problems of TCP over satellite, and the need to provide the best level of service to the warfighters, DISA commissioned defense contractor Booz Allen Hamilton (BAH), along with the MILSATCOM section of the Joint Terminal Engineering Office, to conduct an analysis of several industry leading PEPs.[27] PEPs reviewed were Mentat's SkyX Gateway, Lineo's VPN Router, and COMSAT CLA-2000. SkyX was tested using their original product (Express Transport Protocol (XTP)), minus the compression features instead of its newly released SCPS compatible version. The test concept was to transfer a single 50 Mb file using FTP, across the satellite simulator, and assess to what degree each PEP maximized the available channel.[28] From the results this and following DISA/BAH PEP tests of multiple vendors, the SCPS based Comtech Turbo IP PEP was chosen to be fielded at each STEP/Teleport.

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[27] A Study On Overcoming TCP/IP Latency and Path Delays with High Bit Error Rate Effects on Data Networks over Satellite Communication Paths, MSgt Robert Willett, Sept, 07,2003

[28] *Performance and Compatibility Verification Test Plan for the Defense Information Systems Agency Standardized Tactical Entry Point*, Booz Allen Hamilton Corporation, November 18, 2002

a. Interoperability

Tactical users pulling DISN services from a STEP site desiring to use PEPs must use the SCPS standard. Since DISA's decision to use the SCPS protocol, several competing PEP vendors who use proprietary solutions have developed and released a SCPS version of their product. Of particular interest are Expand and SkyX, whose proprietary products also feature the benefits of compression and/or caching. During the Joint User Interoperability Communications Exercise 2004 (JUICE 2004), the DISA STEP Program Office verified interoperability of SkyX's SCPS version with the Comtech Turbo IP at the STEP.[29] The Xiphos Xiplink and Hotlens Turbobooster were also verified as compatible. During the PEP evaluation conducted by the author and MCTSSA, Expand's new SCPS version was also proven compatible with the Turbo IP.

Many G-6 representatives seem to be convinced that they are required to purchase the Comtech Turbo IP for STEP shot entries, and have the option to purchase other products for internal links. However, it is not the vendor mandated by DISA, it is the protocol. The Marine Corps has the option of purchasing a device that does both SCPS (on STEP entries), as well as compression, caching, and QoS on internal links, all in a single box. The advantages of this approach are significant in terms of product support and maintenance, and training.

[29] MSgt Robert Willet, *Space Communications Protocol Standard – Transport Protocol (SCPS-TP) Interoperability Testing for the Joint User interoperability Communications Exercise (JUICE) 2004 Test Report,* Defense Information Systems Agency, Satellite Tactical Entry Point Program Office, Sept 11, 2004

F. THE BEST SOLUTION: A LAYERED APPROACH

The preferred method of maximizing bandwidth and throughput is through a layered approach that targets several layers of the OSI model, instead of just one. The SCPS protocol (layer 4) may overcome TCP limitations, but can only give approximately the full data rate allotted to the channel, i.e., 256 or 384 Kbps. Even if the maximum bandwidth of the channel is achieved, it remains insufficient for supporting the number of users found in a Division COC or higher headquarters. SCPS alone also does nothing to enhance other transport protocols, such as the growing percentage of UDP (User Datagram Protocol). UDP supports applications such as streaming audio and video, MPEG files, and Voice Over IP (VoIP), and is becoming more and more a significant portion of the network traffic as the dependency on aircraft and satellite imagery increases. An analysis of NTAS traffic during OIF II, dated 5 January 2005, reveals UDP traffic more than doubled TCP traffic on an LMST link between the MEF and the 24th MEU.[30] Using SCPS alone to optimize TCP would have little bearing on improving a link of this nature, however, the addition of compression would. A recent PEP test conducted for the White House Communications Agency (WHCA) by the Naval Research Laboratory demonstrates the compressibility of UDP: "Of the devices tested with compression, Expand Accelerator increased the throughput in our UDP test from 2 to 12.4 Mbps, which is a 603% improvement in throughput of

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[30] Author maintained the capability to view MEF's SIPRNET NTAS from the NPS STBL (Secure Technologies Battle Lab). The date was chosen as a random sample.

the UDP data.[31] A layered combination of TCP enhancement, compression, caching, QoS, and proactive network monitoring can greatly improve performance of the system as a whole.

The simple diagrams below compare a non-optimized system with one using a multilayered optimization approach. Figure 6 depicts a Gigabit backbone LAN becoming bottlenecked. If data destined for transmission outside of the LAN is sent to the router faster than it can be processed, data becomes stacked in the queue. If no QoS is configured, the router directs packets using a First In, First Out (FIFO) queuing strategy. The data can only be processed as fast as the allotted bandwidth allows, and in no order or precedence.

For comparison, Figure 7 illustrates the benefits of PEPs, compression, caching, and QoS. Caching reduces the amount of traffic required to be sent over the satellite link, and compression reduces the aggregate amount of data before transmitting. QoS policies ensure priority traffic is processed first, and TCP enhancement ensures the max available bandwidth is utilized. The result is an opening of the bottleneck, creating a more even flow of data.

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[31] Naval Research Laboratory, Information Technology Division, Satellite and Wireless Networking Section, Code 5554, *Satellite Acceleration Test Report*, pg 18, November 14, 2004.

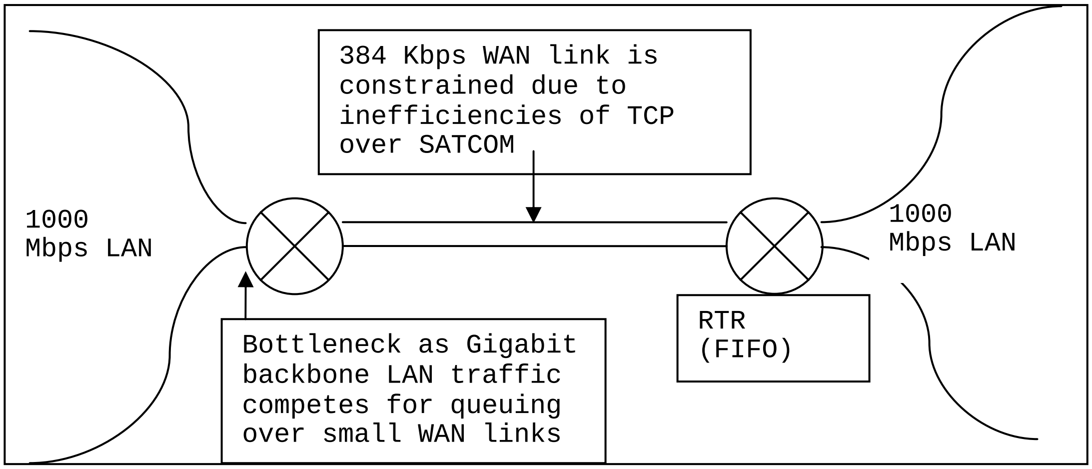

Figure 6. Un-optimized Network Concept

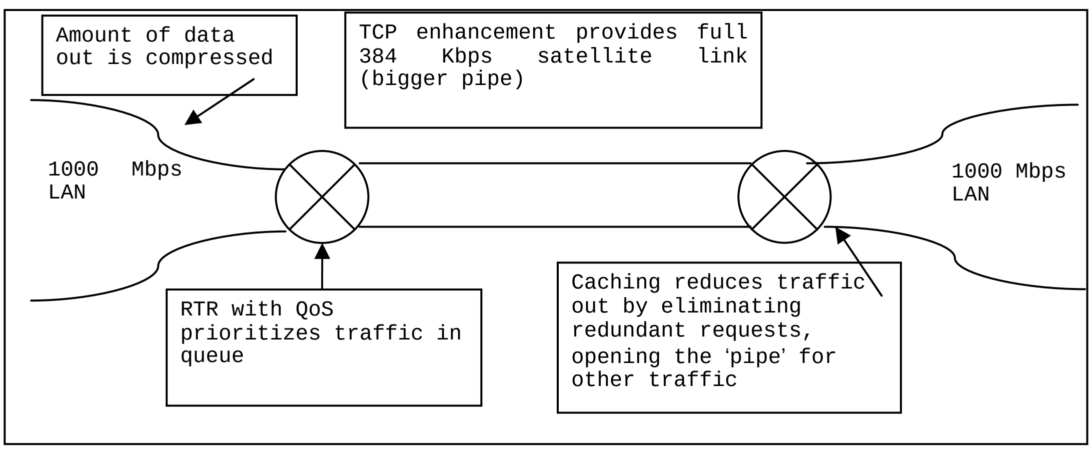

Figure 7. Multilayered Optimization Concept

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IV. PEP EVALUATION

Figure 8. PEP Size Comparison to a 2U Dell Server

A. INTRODUCTION

From 16-17 December, 2004, MCTSSA hosted a technical evaluation of various WAN enhancement vendors in order to provide data for this thesis, and to validate a testing strategy for future MCTSSA tests of PEP technologies.

1. Test Participants

Two of MCTTSA’s Systems Engineers, Mr. Paul Nyenhuis and Mr. Rickey Graham, provided outstanding technical support by validating test objectives and configuring the lab and associated equipment. Four top PEP vendors: Expand, Peribit, Mentat, and Comtech, were invited to participate in the experiment based on exceptional performances in previous similar evaluations. All vendors sent engineers to assist, with the exception of Comtech, which was able to provide equipment, but not personnel due

to previous commitments. Figure 8 illustrates the size comparison of each compared to a 2U Dell Server (on bottom). The key features of each vendor’s products are represented in Table 1.

Vendor	PEP / TCP Enhancement	Compression	Caching	QoS/Bandwidth Management	Network Monitoring and Analysis
SkyX	X	X		[32]	
ComTech	X				
Expand	X	X	X	X	X
Peribit	X	X	X	X	X

Table 1. Technologies Featured by Vendor.

2. Previous PEP Tests

Although many similar PEP evaluations have been conducted, none used a testing strategy that validated the use of SCPS on a network resembling the characteristics of a USMC tactical network. Most of those reviewed used only a single FTP session across an unsaturated satellite link as the sample, and measured improvements SCPS provided to file transfer speed. This method does not relate well to determining the benefits of PEPs on the typical highly saturated USMC tactical networks. Only one of the tests reviewed considered testing with multiple simultaneous TCP connections. However, it was only 10 FTP sessions from a single client across a T-1 (1.544 Mbps) at 750ms delay to determine how various PEPs allocated the bandwidth. The test demonstrated the SCPS Transport Protocol’s ability to fully utilize all the bandwidth that may go unused on a

[32] SkyX plans to release Packeteer’s QoS features in 3rd Quarter, 2005. SkyX (Mentat) was purchased by Packeteer in Dec 2004.

normal TCP based link. However, providing all available bandwidth does not help much when the link is 98% consumed. For example, NTAS data from 0200 to 0600, 09 November 2004, revealed a range of 91 to 98 percent utilization on one of I MEF’s GMF links. None of the tests reviewed measured the impact of SCPS on a highly saturated, low bandwidth link with multiple users, simultaneous TCP connections, and multiple protocols, mandating the conduct of this evaluation.

3. Purpose

There were several purposes for conducting this evaluation:

a) To assess performance improvements using a test bed that is more representative of a USMC tactical network, where multiple simultaneous TCP connections, users, and protocols saturate the satellite link,

b) To capture tangible data (percentages of improvement) to reflect in the optimized NETWARS model,

c) To evaluate interoperability of Expand’s Beta release of SCPS with the STEP site’s Comtech Turbo IP PEPs,

d) To validate MCTSSA’s testing configurations and utilities, such as Spirent’s Smartbits and VLAN configurations in preparation for a more thorough MCTSSA PEP evaluation planned for the Spring of 2005,

e) To determine if there is an “all-in-one” solution for USMC tactical WAN/LAN management.

B. NOTES ON THE TEST SUBJECTS

1. Comtech Turbo IP

The Turbo IP accelerators are the PEP's chosen by DISA to put online at the STEP sites. For interoperability purposes, the Turbo IP addresses only TCP enhancement, and features no caching, QoS, or compression. The web based GUI proved simple to configure in just a few short steps.

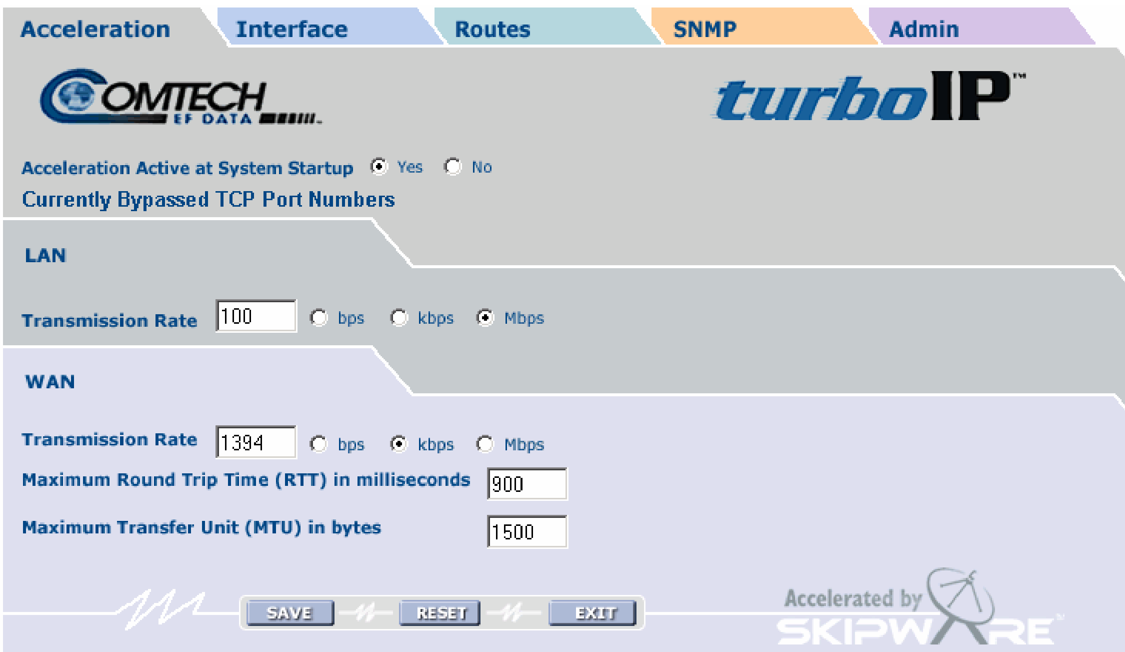


Figure 9. Comtech Turbo IP GUI Screenshot

An autonegotiation feature determines if the distant end is SCPS enabled. If so, the SCPS implementation is activated. If SCPS is not detected, the Turbo IP reverts to regular TCP. This concept is generally referred to as Failover Pass-through.

2. Mentat's SkyX Gateway

All previously conducted tests, to include those conducted by BAH, featuring the SkyX Gateway tested their proprietary XTP (Express Transport Protocol) version, with the exception of a DISA interoperability test conducted

shortly before this evaluation.[33] The DISA test confirmed interoperability of Mentat’s new beta version (5.0) of SCPS with the Turbo IP. However, the SCPS beta version on the XR-10 model used for this evaluation proved problematic for reasons undetermined, but was most likely due to an incompatibility with the way Smartbits handles SACKs (Selective Acknowledgments). Mentat made known the immaturity of version 5.0 in advance, and was willing to support the evaluation for demonstration purposes. Their proprietary version was employed by I MEF during OIF I.

In December 2004, one week after the MCTSSA evaluation, Mentat was acquired by the application management company Packeteer. In January, Packeteer announced the full release of SkyX version 5.0, which offers users the capability to implement SCPS or XTP in a single box. For better performance on internal links, units can implement SkyX’s XTP, compression, congestion control, and Forward Error Correction features, but use SCPS on STEP shots or with other SCPS devices. When using the SCPS only version, users can still employ the XTP congestion control capability. For compression, SkyX uses the open-source Deflate algorithm. Configurations are made using the Command Line Interface (CLI).

3. Expand

Expand’s Accelerator 4800, version 5.04 was Expand’s first SCPS effort. Their proprietary version was employed during Exercise Millennium Edge 2002, where they “measured significantly higher data rates and prioritized services

[33] MSgt Robert Willet, *Space Communications Protocol Standard – Transport Protocol (SCPS-TP) Interoperability Testing for the Joint User interoperability Communications Exercise (JUICE) 2004 Test Report,* Defense Information Systems Agency, Satellite Tactical Entry Point Program Office, Sept 11, 2004

across existing WAN links… transforming a 64Kbps link into a virtual 256Kbps link, and a 128Kbps link into a virtual 512Kbps link.[34] The 24th MEU and I MEF also employed Expand Accelerators during OIF I.

Expand's web based GUI offers real-time charts and graphs for monitoring performance, such as depicted in Figure 10.

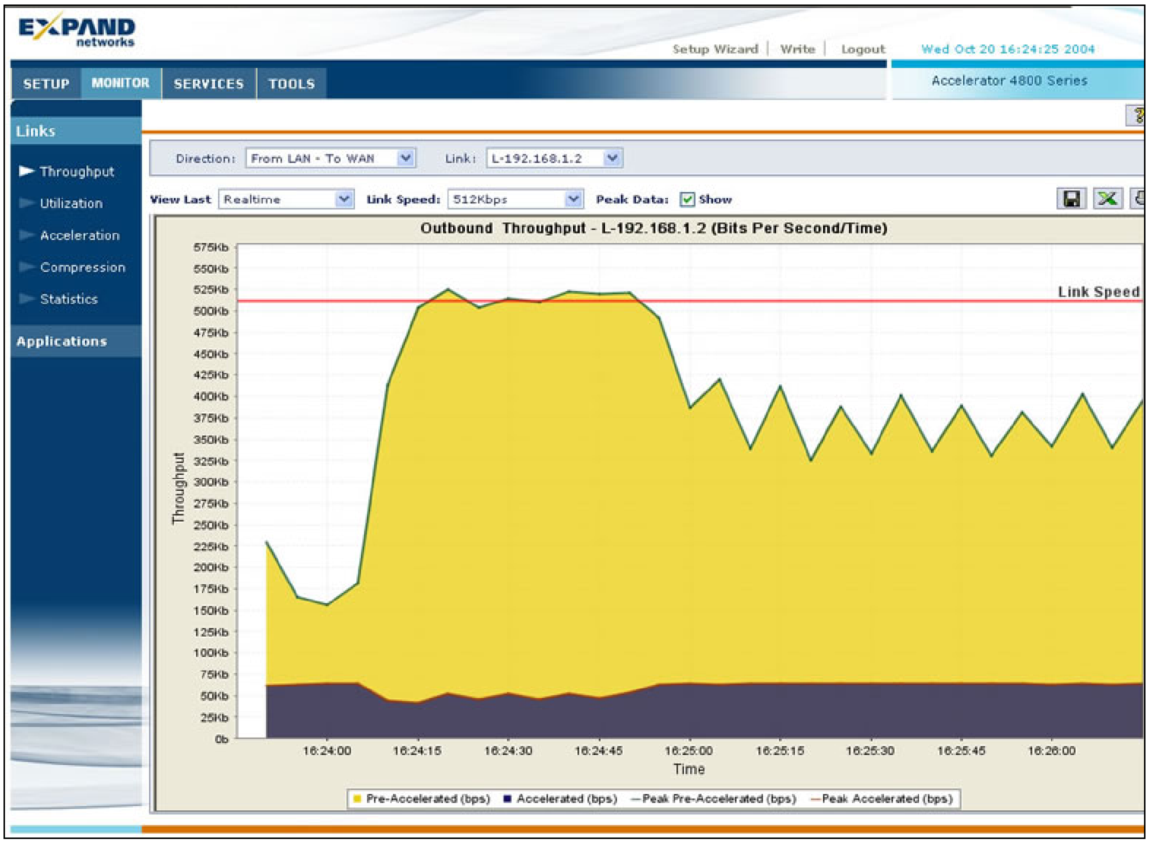


Figure 10. Expand Performance Monitoring GUI

4. Peribit

The SM-500 version of Peribit tested featured a 500 Gb hard drive to facilitate is caching dictionary. It is SCPS

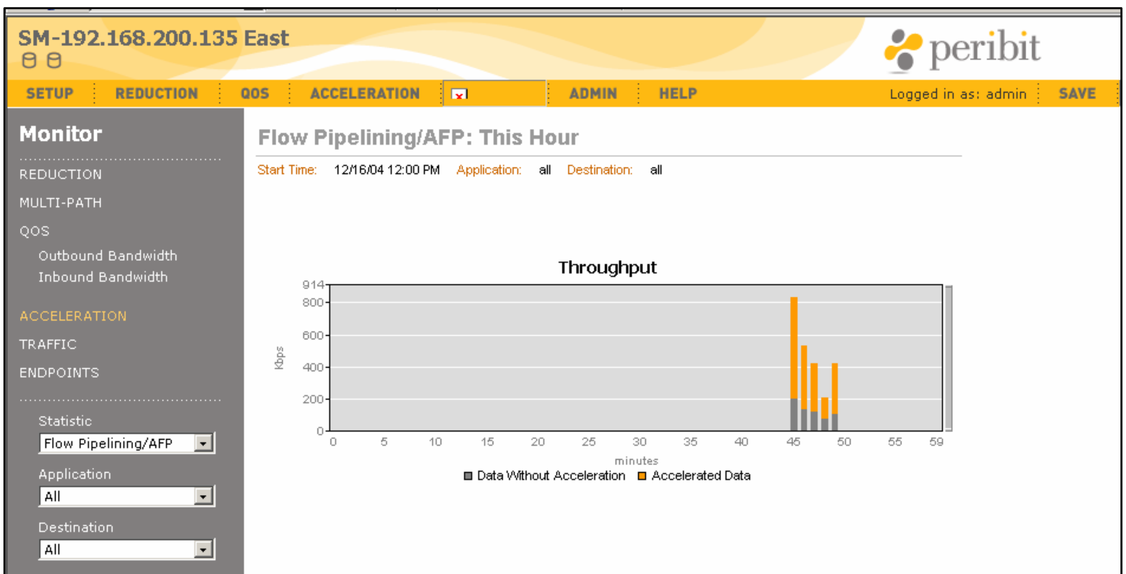
[34] *US Joint Forces Command Selects Accelerators For Millennium Challenge 02 Exercise*, Case Study for US Joint Forces Command http://www.expand.com/include/casestudy/JBC.pdf

Millennium Challenge 02 Exercise

compliant, but since compression cannot be disabled, it only works with other Peribit systems and cannot be used for STEP shot entries. The six step configuration process through Peribit's web-based GUI proved quick and simple to set up. Radio buttons allow configuration options such as Forward Error Correction, QoS features, and 802.1q VLAN

support. If vendors do not support 802.1q, compression will only occur on the VLAN on which the Peribit unit resides.

Peribit also features a real time analysis GUI as depicted in Figure 11.



Application	Total TCP Sessions (count)	Accelerated Sessions (count)	Traffic (MB)	Average Session Throughput (Mbps) Actual	w/o Accel.*	Acceleration Factor
FTP	56	54	27.49	1.23	0.21	5.9 X
HTTP	404	370	3.35	0.14	0.14	1.0 X
Others	46	37	0.08	0.00	0.00	1.0 X

Figure 11. Peribit Performance Monitoring GUI

C. EXPERIMENTAL DESIGN

1. Physical Lab Design:

The MCTSSA testing lab is designed to represent an "East Coast" LAN connected to a "West Coast" LAN through a

satellite simulator. Spirent’s Smartbits, an industry leading network testing and analysis system, is used to generate multi-protocol LAN traffic, and to represent FTP, DNS, and WWW servers as well as over 100 clients. Routers are configured with VLANs to represent additional subnets.

Smartbits (Avalanche) was configured to represent two servers and multiple clients using multiple, simultaneous FTP, HTTP, and streaming video requests. The file sizes of each of the applications were tweaked to nearly saturate the 512 Kbps link. To assess the impact on both satellite and terrestrial systems, the satellite simulator was configured to run tests at both e-5 and e-7 BERs. Tests were first run with 0 delay, then with 500ms RTT. A baseline test with no PEPs was run first as a basis for comparison. Each of the four vendors were put through the sequence of tests. To narrow the volumes of data collected, and to focus more on the scope of this thesis, only data from the tests run at 512 Kbps, 500ms RTT, and e-5 BER is represented herein.

The following equipment was used, and is represented in the test topology in Figure 12:

1 – Adtech SX-13A satellite simulator
2 – Cisco 3745 routers with Switchblade
2 – Cisco 3750 layer 3 switches
2 – SmartBits with Smart Flow and Avalanche
3 – Laptops for SmartBits consoles and HyperTerminal
2 – Distributed Sniffers for RMON capture

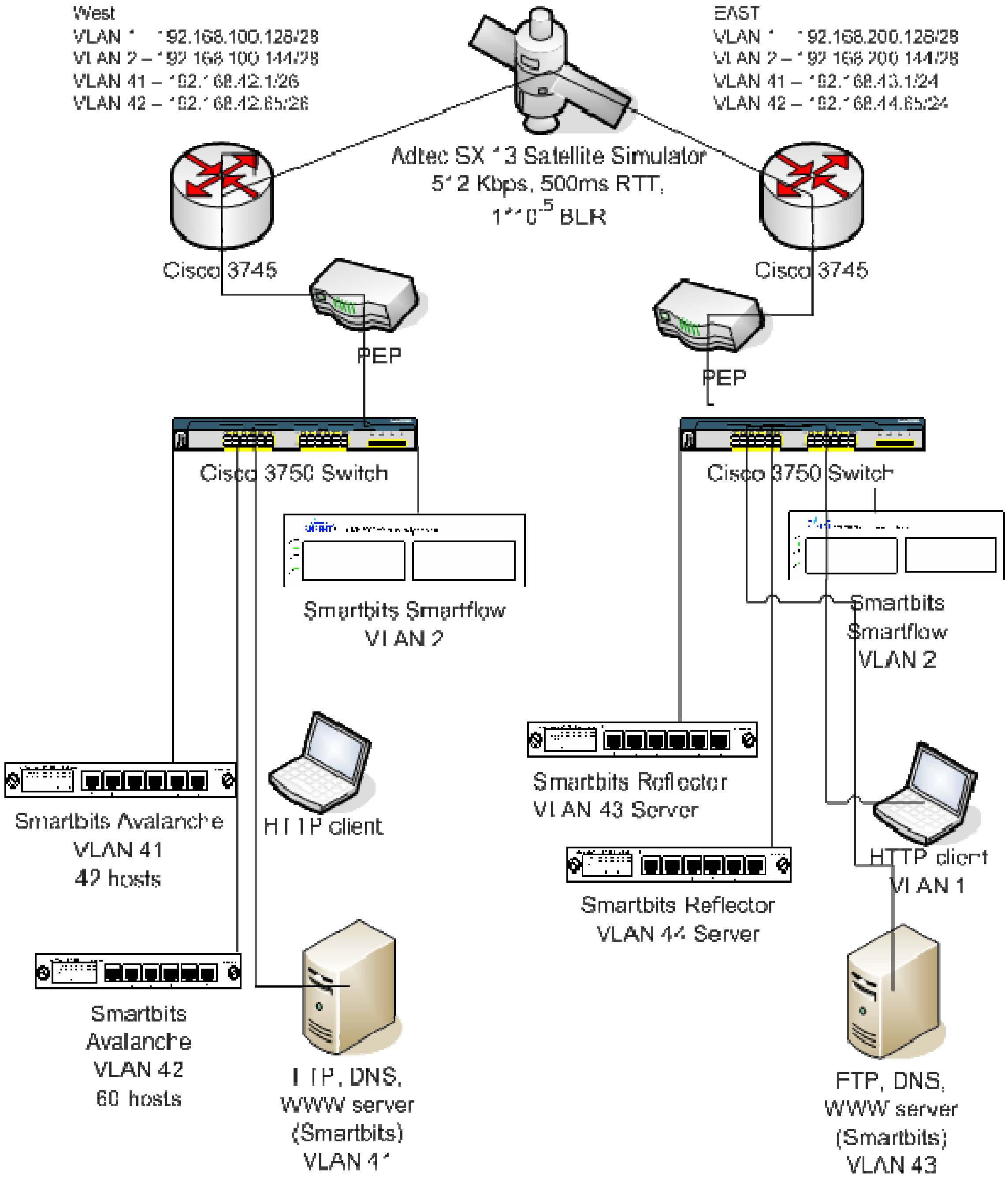


Figure 12. MCTTSA Lab Configuration

D. DATA DESCRIPTIONS

Smartbits collected statistics for each five minute test run in the form of CSV files (Comma-delimited Separated Values), which were imported into Microsoft Excel. The raw data and accompanying graphs follow.

BASELINE			COMTECH TURBO IP	
Attempted Transactions	198		Attempted Transactions	231
Successful Transactions	184		Successful Transactions	183
Total HTTP Completions	164		Total HTTP Completions	161
Total FTP Completions	0		Total FTP Completions	4
Total FTP Attempts	10		Total FTP Attempts	10
Total Stream Completions	20		Total Stream Completions	18
Incomplete Streams	4		Incomplete Streams	2
PERIBIT			**EXPAND (Proprietary Version)**	
Attempted Transactions	488		Attempted Transactions	344
Successful Transactions	478		Successful Transactions	337
Total HTTP Completions	404		Total HTTP Completions	284
Total FTP Completions	28		Total FTP Completions	18
Total FTP Attempts	28		Total FTP Attempts	20
Total Stream Completions	46		Total Stream Completions	35
Incomplete Streams	10		Incomplete Streams	5

Table 2. Overview of PEP Test Results

No results could be obtained for Mentat’s SKyX due to technical problems with Smartbits and the beta versions being tested. Expand with SCPS demonstrated similar problems with the FTP portion. However, using only HTTP traffic, the SCPS version of Expand was verified to be

compatible with the Turbo IP. The Expand data above represents Expand’s proprietary solution on each end for demonstrative purposes.

E. ANALYSIS

The following table illustrates percentages of improvement for the number of successful transactions:

Successful Transactions		**% Increase**
Baseline	184	
Turbo IP	183	-0.54%
Expand	337	83.15%
Peribit	478	159.78%

Table 3. Percentage of Transactions Above Baseline

All variables, such as bandwidth, latency, BER, and traffic, were held constant as each PEP was tested. The more efficient the link is, the more transactions TCP will attempt.

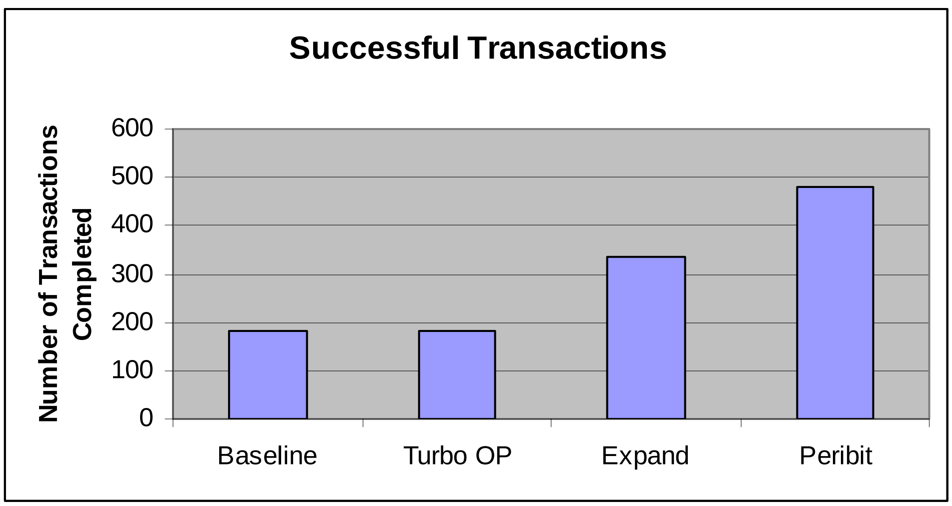


Figure 13. Transactions Completed

As expected, Expand and Peribit’s compression and caching schemes (respectively) allowed far more transactions than SCPS alone. According to the data, the SCPS only Turbo IP demonstrated no improvement over the

baseline. This demonstrates the inability of SCPS to improve a link that is saturated at maximum or near maximum capacity.

Whereas the maximum throughput SCPS could have provided, whether the link was congested or not, is the full 512 kbps of bandwidth, the caching technology of Peribit increased the perceived throughput to 1.2 Mbps.[35]

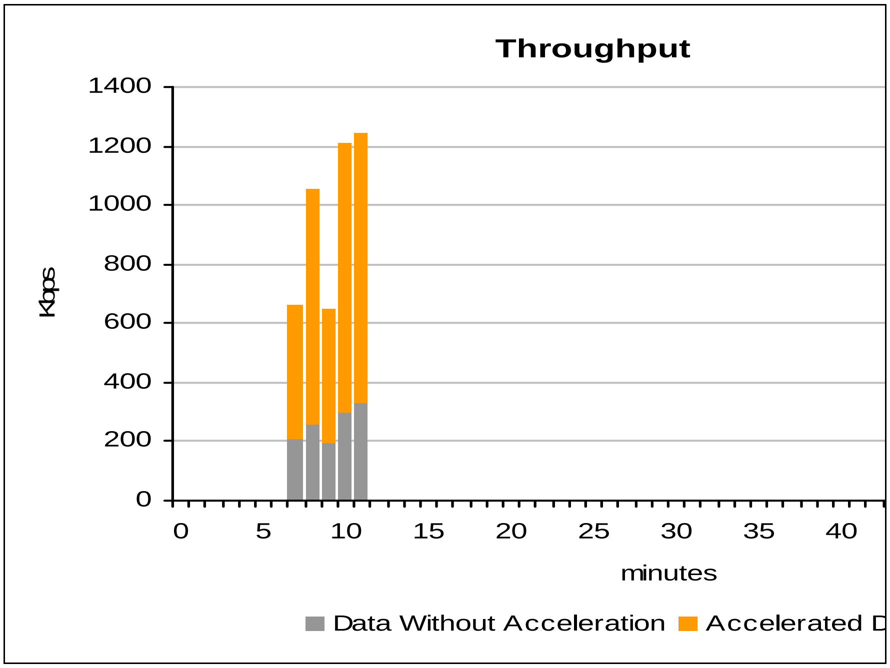


Figure 14. Peribit Acceleration Rates

To put the benefit of this improvement in perspective of costs, this data rate is close to the 1.544 Mbps SIPRNET circuits currently being leased by I MEF in Iraq.[36] I MEF leased three 8Mb (aggregate) Ku band terminals at a cost of 12 million dollars per year. Using Peribit SM-500s, three DSCS links could have been optimized for a one time

[35] Figure 13 and Table 4 were constructed using Peribit's CSV Analyzer, version 5.0.8.

[36] Costs for Ku band terminals provided by Captain Billy Cornell who deployed with I MEF G-6 during OIF I. Also confirmed by Lt Col Mark Bryant, MARCENT G-6 Operations Officer during OIF I.

purchase price of about 70,000 dollars, or less than a few days worth of fees paid for the leased Ku band terminals.

The accelerators would also be available for future exercises and operations, where as the leased terminals are not owned by the USMC.

	Total TCP Sessions	Accelerated Sessions			Average Accelerated Session Throughput (Mbps)		Estimated Acceleration Factor
Application	(count)	(count)	(percent)	(MB)	Actual	w/o Accel*	
FTP	56	54	96.4%	27.49	1.41	0.24	5.9 X
HTTP	406	373	91.9%	3.37	0.14	0.14	1.0 X
Others	46	40	87.0%	0.09	0.00	0.00	1.0 X

Table 4. Peribit Acceleration by Protocol

It should be noted that Peribit's caching method, coupled with the way Smartbits was configured to send redundant 9k HTTP files and 1mb FTP files, may have skewed the results. After Peribit caches data on its 500 gigabyte hard drive, it represents that bit pattern with a 4 byte symbol. Peribit serves future network requests matching the cached data by sending only the symbol. Since the Smartbits data was redundant, it is possible that only 4k responses were traversing the WAN link. However, the data pertaining to Peribit and Expand is consistent with the findings of a November 2004 Network Computing magazine WAN acceleration vendor assessment.[37] Expand reduced the latency time from 950 ms to less than 300 ms, and Peribit reduced it to around 100 ms. The faster the ACKs are received, the sooner TCP can retransmit the next burst of packets.

[37] Mike DiMaria, *WAN Accelerators, Breaking the WAN Bottleneck*, Network Magazine, Nov 25, 2004

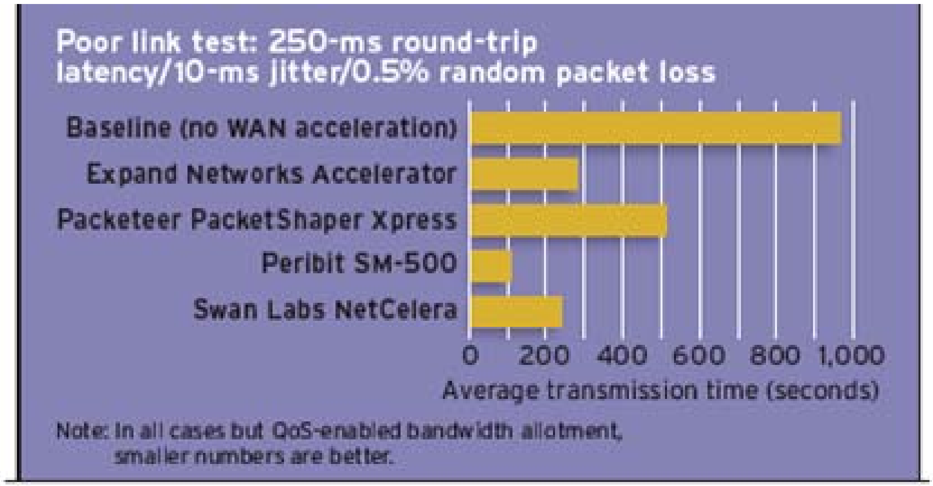


Figure 15. Network Computing Magazine Test Results With 250ms RTT (from Reference 37)

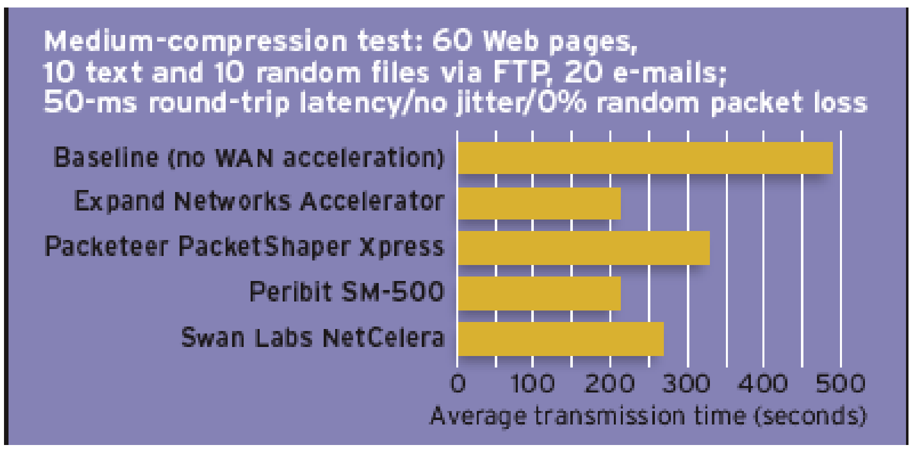


Figure 16. Network Computing Magazine Test Results With Multiple Files and Protocols (from Reference 37)

F. CONCLUSIONS

Peribit clearly out performed the competition, however, SKY X and Expand were testing beta software versions implementing SCPS-TP. Full versions have since been released. Although the SCPS version of Expand was not fully tested, tests were conducted using their proprietary version. Potential problems with Smartbits' support of Selective Acknowledgements (SACK) are being considered by engineers from both Smartbits and the vendors to determine the cause. Therefore, results of this experiment are

inconclusive with respect to recommending a SCPS based PEP for the Marine Corps, but does illustrate the compounding benefits of a layered optimization approach over the use of SCPS alone.

As with any other proprietary solution, Peribit could be used to optimize internal Marine Corps links. The SM-500 has the capability to recognize whether inbound circuits contain a like device. If so, traffic is optimized. If not, it reverts to normal TCP methods for that circuit, providing interoperability with any systems not using Peribit. However, because caching cannot be disabled on Peribit units, they are not currently a viable option to interface with Comtech Turbo IPs at the STEPs.

Since this evaluation, SkyX has announced the full release of their SCPS version. Making configurations changes through the CLI allows users to implement SCPS only on STEP entries, or XTP with compression and congestion control on internal links. The compression features help to optimize other protocols not addressed when using SCPS alone, such as UDP traffic.

G. RECOMMENDATIONS

Rather than purchasing Turbo IP accelerators for STEP shots, and another all-in-one solution for internal links, as organizations such as III MEF have considered,[38] the study demonstrates that units could purchase a single product that can do both. Doing so would require less training, costs, and support requirements, and offer more flexibility than purchasing two separate systems. DISA's decision to optimize the WAN link with SCPS focuses only on

[38] LtCol James M. Breitinger, SUBJ: *RE: FW: Request for Information.* III MEF intended to purchase Expand Accelerators for internal links, Turbo IP's for STEP shot entries.

the satellite link and deprives tactical communicators of further optimizing their STEP shots with products that have better performance and more features, such as compression, caching, and QoS. Even though internal links can be optimized as desired, traffic destined through the STEP site will still be constrained to the maximum bandwidth of the circuit, potentially creating bottlenecks for traffic going through the STEP. Understanding DISA’s requirements for open-standards to support interoperability, perhaps an open-standards compression scheme, such as Deflate in conjunction with SCPS is a viable option.

MCTSSA’s engineers intend to conduct follow-on testing, implementing adjustments to the testing methodology such as lab design and adding actual clients and servers to the network. Rather than relying solely on test tools to generate network traffic, actual clients performing prescribed tasks will produce more realistic results.

V. MODELING AND SIMULATION OF CURRENT AND OPTIMIZED TACTICAL SYSTEMS USING NETWARS

A. INTRODUCTION

The Command and Control Research Program's (CCRP), Code of Best Practice for Experimentation provides guidance on producing usable models, reminding readers of George E.B. Fox's quote that, "all models are wrong, some are useful."[39] Although most readers could ably deduce that lowering latency and reducing traffic loads will result in better network performance, this modeling and simulation effort is intended to provide a 'useful' statistical and graphical representation of the improvements.

1. About NETWARS

An explanation of NETWARS is best given by its developers, Booz Allen Hamilton:

> NETWARS is the Joint Standard, C4 Modeling and Simulation tool that has been developed by the Joint Staff J6 in partnership with the Defense Information Systems Agency (DISA) to enable C4 planners and analysts to construct communication architectures, validate communications support plans, analyze existing and proposed network architectures, and evaluate the performance of new communications devices and applications. NETWARS has been developed to perform these functions at the strategic, operational, and tactical levels in support of operational planners, analysts, and acquisition communities. Output from NETWARS can be useful for commanders, planners, and analysts in determining which communications systems might be overloaded during selected times in a particular scenario and can assist in making prudent architecture design and acquisition planning decisions.[40]

[39] DOD Command and Control Research Program, Code of Best Practice for Experimentation, July 2002, p.401.

[40] NETWARS Software Documentation Manual, version 2005-1.

NETWARS runs on OPNET's simulation engine, and is very similar to OPNET with the exception of being more militarily focused. An OPNET Simulation Runtime license is not included in the standard NETWARS license. However, OPNET provided a temporary academic license to facilitate this experiment. The Simulation Runtime license was required to actually run the simulations.

a. An Overview of NETWARS- "How it Works"

This overview is to familiarize the reader with the terminology used in the proceeding paragraphs, and provide a conceptual understanding of how a simulation is constructed and analyzed. Within NETWARS, the top level view shows the Organizations to be represented in the model. Within each Organization, OPerational FACilities (OPFACS) are created to represent collections of communications devices, which virtually perform functions of actual communications equipment. The devices are selected from a library known as the Object Pallet, and linked by selecting the appropriate link type. Data rates, user profiles, and traffic are also configured, allowing 'loaded' traffic to be routed between hosts. The simulation is then run to produce the selected statistics.

There are many more options, functions, and capabilities within NETWARS, however, only those pertinent to this scenario are introduced for the sake of brevity.

B. ARCHITECTURE AND METHODOLOGY

NETWARS, version 2005-1, is used to demonstrate in a more tangible presentation the performance expectations of a layered optimization strategy over the Marine Corps' current practices. Once the architecture is constructed, it can be altered to analyze various "what-if" scenarios.

The first set of scenarios analyzes current system performance with no optimization. In the second set of runs, the architecture is modified to represent the improvements observed during the PEP evaluation at MCTSSA.

Because modeling and simulation is abstract and conceptual in nature, a simple architecture is used to illustrate the concepts being presented. Site A and Site B represent two separate LANs, such as between the Division and the Marine Air Wing, connected by a 256k point-to-point WAN link typical of a tactical SIPRNET or NIPRNET circuit. The tests were also run at 512k to demonstrate the effects on a link with greater bandwidth. Clients are connected to the backside of each router, and configured to generate application specific traffic, i.e., the EMAIL_A device generates a high load of SMTP traffic across the WAN link.

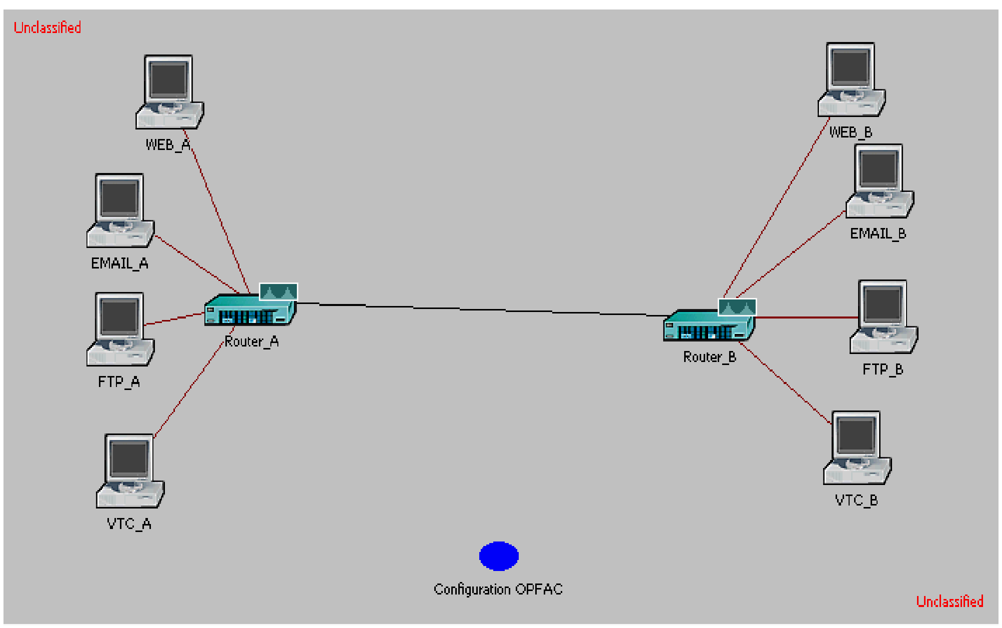


Figure 17. Network Topology

The delay on the satellite link and the application attributes are varied in order to analyze system performance. Link utilization, link load and application download times are used as the performance metrics in all comparisons.

1. Traffic

There are several methods to represent traffic, such as background loading percentages, the Application Configuration Utility, and importing actual traffic collected from a network.

To import data collected using Ethereal or NTAS, an IP map which maps every IP on the system to its source, must be known. Most tactical networks contain multiple separate networks (SIPRNET, NIPRNET, and often a coalition network) each at the MSC level, amounting to thousands of IP addresses. NTAS data requires a script to import, which was not available, and Ethereal data must be converted to ACE threads to import. Due to these issues, as well as concerns with classification of the data, this technique was not employed as originally intended. Instead, the traffic was constructed manually through the Application Configuration Utility based on traffic patterns observed during UFL 04, CG04, and OIF II. NTAS data confirmed the top four protocols of these networks as HTTP, SMTP, FTP, and UDP.

2. Modifications to Represent Optimization

There is no single number that represents the percentage of performance increases of a layered optimization strategy. There are far too many variables such as protocols, applications, and the percentages of each to generalize a “typical” traffic profile. Each file

type (i.e., .doc, .ppt, .jpg, .mpeg, etc.) and protocol (i.e., HTTP, FTP, UDP, etc.) varies in compressibility. Improvements by caching are dependent on the amount of redundant data being requested. Improvements through SCPS depend on how saturated the link may be, as well as what percentage of that traffic is TCP. UDP traffic is not affected by SCPS, but may be compressed and/or cached. To represent compression and caching, the applications traversing the network were reduced from a heavy load to light within the Application Configuration Utility.

Because no ready-made PEP device exists in the NETWARS Object Pallet, the effects of PEP were represented by adjusting the latency times. A standard 250ms one-way delay represents a link without PEPs. To represent the PEP, the delay was reduced to 5ms, intending to resemble the effect of a PEP producing the quality of a terrestrial link. The traffic is configured at a high load at 250ms, and a lighter load at 5ms.

Case 1 at 250ms represents the baseline, with no compression, caching, or PEP for TCP enhancement. Cases 2 and 3 are omitted for brevity and relevance. Cases 4 and 5 were configured with less traffic load to represent compression and caching, and latency reduced to 5ms to represent TCP enhancement. Cases 4 and 5 differ only in that Case 4 omitted the VTC traffic profile to represent the compression and caching of UDP traffic, where as Case 5 includes the VTC profile to represent the added traffic of an actual VTC over IP session being conducted while normal network activity resumes currently.

Because UDP traffic is not optimized by SCPS-TP, but still comprises a percentage of the traffic traversing the

tactical networks, compression and caching must be employed to reduce the effects of UDP. The capability of using compression and caching to minimize UDP traffic was demonstrated by the Naval Research Laboratory PEP experiments in which they experienced a 600 percent reduction in perceived UDP load using compression and caching.[41]

C. ANALYSIS

The following graphs produced in NETWARS depict margins of improvement for each of the primary applications. The graphs do not include labels for the x and y axis. To clarify the graphs, the x axis shows the progress of the runs throughout the eight hour test period. The y axis is in seconds.

Figure 18 demonstrates the performance improvements to TCP based applications using HTTP response times as an example. Case 1 (blue) clearly shows slower response times. Case 4 (red) demonstrates improvements to response times over case 5 (green) when UDP traffic is reduced to null.

The results consistently demonstrate better application response times using a multilayered optimization approach. Figure 20 depicts the delta of case 5 at 250ms (no PEP) verses 5ms (with PEP). Other application response times are also depicted below.

[41] Naval Research Laboratory, Information Technology Division, Satellite and Wireless Networking Section, Code 5554, *Satellite Acceleration Test Report*, pg 18, November 14, 2004

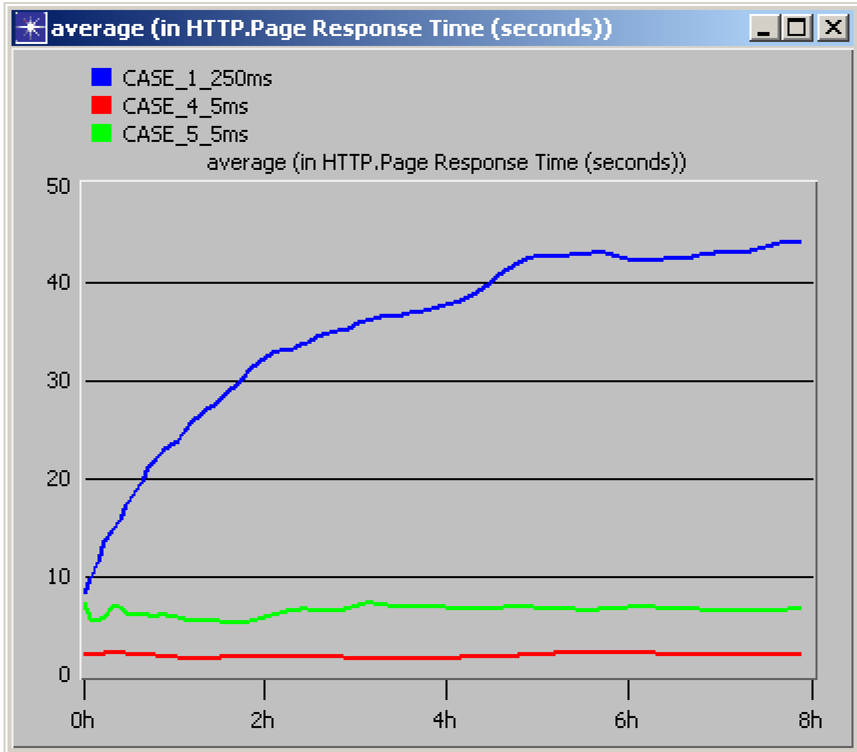


Figure 18. HTTP Response Times

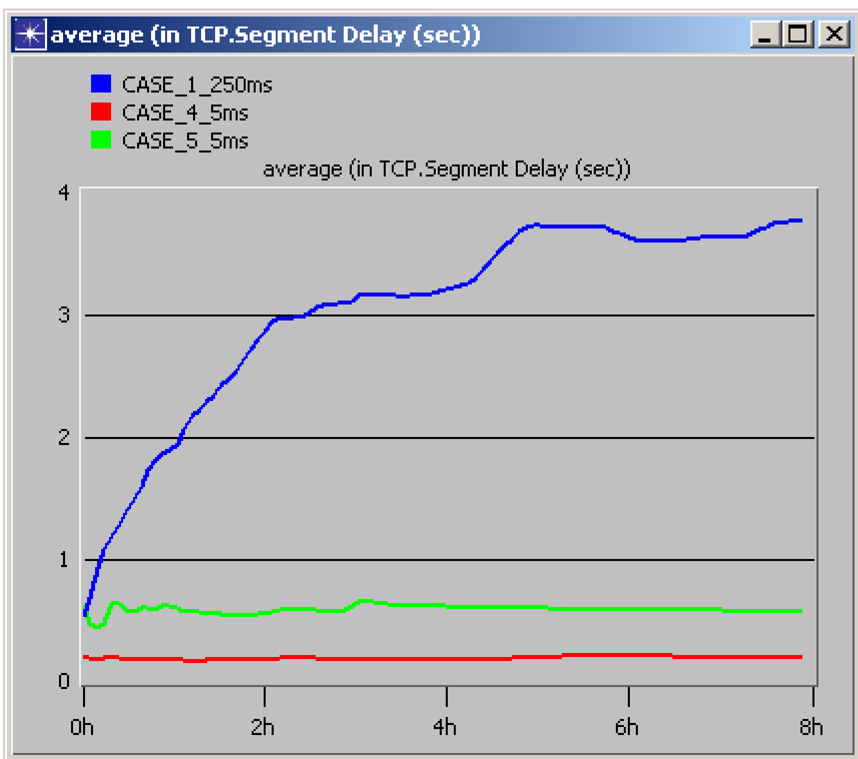


Figure 19. TCP Segment Delay Reduction

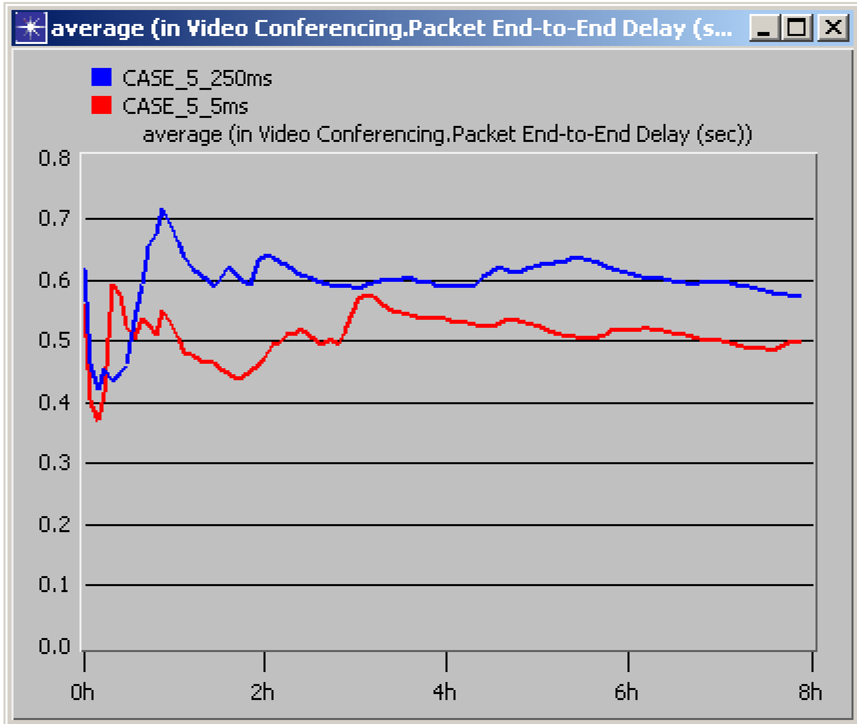


Figure 20. Reduced VTC Delay

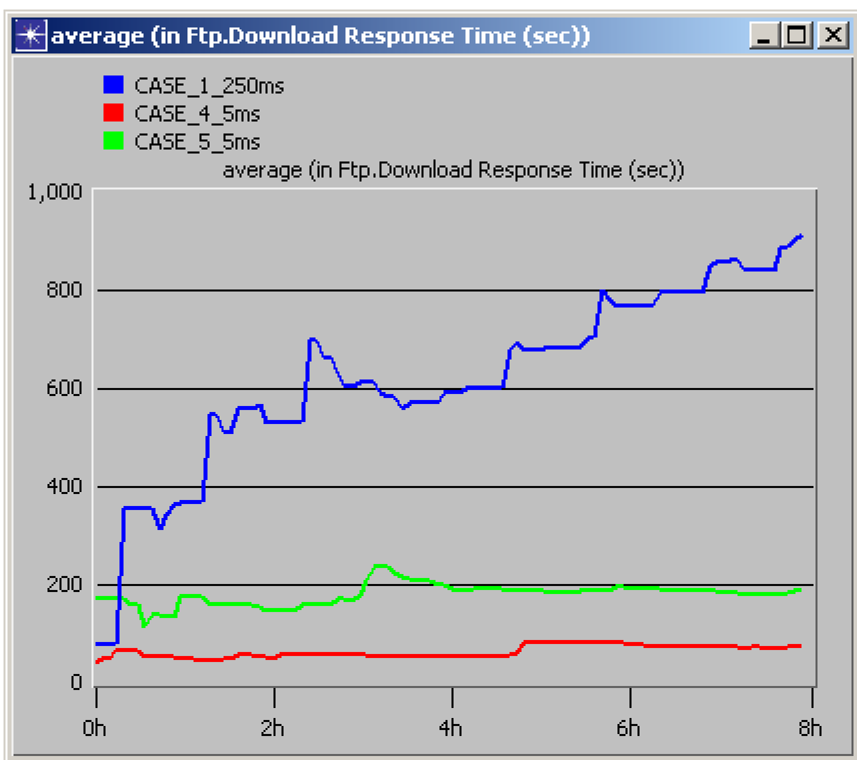


Figure 21. FTP Response Times

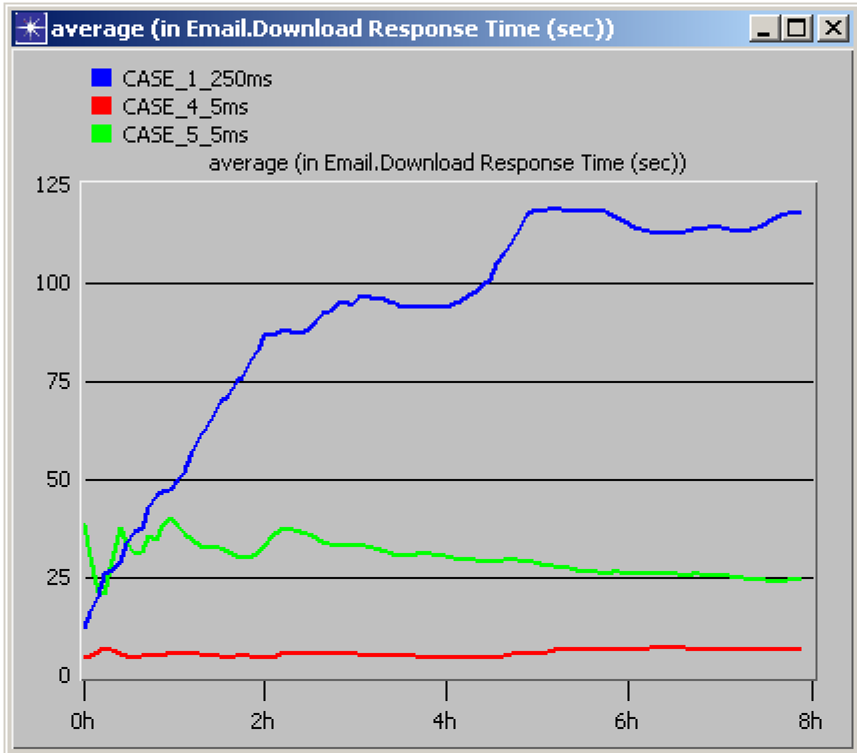


Figure 22. Email Response Times

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VI. CONCLUSIONS

Given the crucial role communications systems play in information superiority and commanding and controlling the battlefield, bandwidth has become a critical asset requiring deliberate management techniques. There are many optimization methods that could and should be standard on our tactical systems, but are not. Even without PEP’s, more effort could be made to maximize the capabilities of layer 3 devices, such as implementing purposeful QoS, queuing strategies, and VLANs. These features are standard on most Cisco routers, but require highly skilled Marines to plan and maintain. Advanced training in router management techniques should be taught at the Marine Corps Communications and Electronics School (MCCES) at both an administrator level, and a systems planner level. Router optimization techniques are standard practice on corporate networks, where revenue is affected by network performance. It should also be standard practice on tactical systems, where network performance affects life or death decisions.

While we can currently only employ SCPS on STEP / TELEPORT entries, we can employ a layered combination of TCP enhancement, compression, caching, and QoS to fully optimize internal USMC, and perhaps, with further guidance from the J6 level, Joint tactical systems. The MCTSSA tests and NETWARS simulation results show that using PEPs provides significant improvements in link utilization and application response times in comparison with non-PEP uses of TCP over a satellite. A multi-function PEP that includes compression, caching, and even QoS features increases improvement of both TCP and UDP based

applications beyond the limits of the apportioned bandwidth, such as the Peribit's capability to make a 512k link have nearly the equivalent throughput of a 1.544 Mbs T1 line. A multilayered strategy provides greater perceived throughput and more efficient link utilization on limited bandwidth resources.

Further experimentation is required to recommend a specific product. Peribit, Expand, and SkyX with SCPS capabilities should be evaluated on an actual network, with users conducting a prescribed testing agenda.

Many G6 Officers recognize the capabilities of multi-purpose PEPs and are putting them online. However, units rarely purchase compatible devices, limiting use to their own units. The use of PEPs should be coordinated during the Systems Planning and Engineering phase at a joint level to fully maximize the potential benefits. Until further direction is provided, units will continue to pursue options that are uncoordinated and incompatible with other units. In keeping with the ideas set forth in the recently released FORCENET doctrine, efforts should be made to optimize our whole system of systems.

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